

Offboard Active Surveillance and Communications

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LONG-TERM GOALS

The long-term goals of this work are to conduct feasibility experiments and associated algorithm design demonstrating phase conjugation (time-reversal) concepts which incorporate naturally the temporal and spatial variability of the shallow water environment into active target detection processing and communications.

OBJECTIVES

The objectives of this research are to demonstrate the enhanced operation of offboard active surveillance and communication systems through the use of phase conjugation (time reversal) techniques to enhance echo-to-reverberation-ratio in active sonars and mitigate multipath in acoustic data communications.

APPROACH

This project is a joint effort between MPL and the SACLANT Undersea Research Centre (M. Stevenson).

A phase conjugate "mirror" time reverses the incident signal precisely returning it to its original source location. This phenomenon occurs independent of the complexity of the medium. The time-reversal process can be accomplished by the implementation of a retransmission procedure. A signal received at an array is time reversed and retransmitted. A full water column source array excited by the phase conjugated (time-reversed) signal received at the array position will focus at the position of the radiating target. The medium fluctuations are embedded in the received signal so that if retransmission can occur on a time scale less than the dominant fluctuations, the medium variability will be eliminated since one back propagates and "undoes" the variability.

Two low frequency (~450 Hz) phase conjugation field experiments previously were carried out (FY96 and FY97) in ~125 m water adjacent to Formiche di Grosseto (a small island approximately 100 miles SW of SACLANTCEN). These experiments demonstrated that phase conjugation is both feasible and stable at low frequencies in shallow water and that focusing of the retransmitted energy is possible at ranges of at least 30 km. Also demonstrated was the ability to shift the range of focus to ranges other than that of the probe source by a simple method involving a frequency shift of the received time series prior to retransmission. Lastly, the degradation of focusing with fewer than the full set of

source/receive array (SRA) transducers was investigated and reasonable focusing was demonstrated with as few as 6 SRA transducers at a range of 15 km. Results from the April 1996 and May 1997 experiments appear in [1-4,6].

As an outgrowth of the successful low frequency phase conjugation experiments, ONR sponsored two high frequency (~3.5 kHz) phase conjugation (HFPC) experiments which were carried out with SACLANTCEN in FY99 and FY00. Central to these experiments was a new high frequency vertical array of 29 source/receive transducers operating nominally in the 3-4 kHz band, an underwater pressure case containing the source/receive electronics, and a surface buoy providing battery power, system control, and wireless local area network (WLAN) connectivity [7].

The July 1999 HFPC experiment (also known as FAF-99 or Focused Acoustic Fields 1999) was carried out adjacent to both Formiche di Grosseto and Elba, Italy. The former provided a link to our previous experiments while the latter provided a brief opportunity to explore a new environment. FAF-99 demonstrated high frequency (~3.5 kHz) focusing at ranges out to 14 km, provided an initial look at the use of phase conjugation processing in acoustic communications, and demonstrated the technology of a source/receive array operating as a node on a wireless local area network. A second HFPC experiment was carried out north of Elba, Italy, in May/June 2000. FAF-00 further demonstrated high frequency phase conjugation focusing at ranges out to 21 km in both flat (~125 m deep water) and sloping (~125 m deep water shoaling to ~40 m deep water) coastal environments. Also measured was the stability of the focal region (observed to be on the order of 30 min). Lastly, the use of phase conjugation processing in both active target detection and acoustic communications was demonstrated. Both (artificial) target echo enhancement and reverberation reduction through time reversal focusing were shown feasible as well as the use of phase conjugation processing in acoustic communications with the transmission of BPSK and QPSK sequences over a 10 km range. Results from the July 1999 and May/June 2000 experiments appear in [6, 9-14].

WORK COMPLETED

Further analysis of the FAF-00 experiment data has resulted in recent publication on the environmental influence on FAF processing [11-12], echo-to-reverberation enhancement [13], and acoustic communications [14].

The FAF-03 experiment was carried out with SACLANTCEN in March-April 2003 north of Elba Island, Italy. In addition to carrying out time reversal focusing at 3.5 kHz, the 29-element HFPCA source/receive array hardware [7] was modified to enable operation at ~850 Hz. The accomplishments of FAF-03 included demonstrating the following (at both 850 and 3.5 kHz unless otherwise indicated): (1) successful operation of a new source/receive transducer array (850 Hz), (2) time reversal focusing in Winter/Spring sound speed profiles, (3) reciprocity-based procedure for studying focusing and stability/fluctuations, (4) simultaneous and sequential focusing at multiple depths, (5) multiple-depth (simultaneous) and synthetic aperture time reversal acoustic communications (3.5 kHz), and (6) reverberation nulling without explicit use of a probe source.

RESULTS

During FAF-03, a reciprocity-based procedure was implemented to facilitate focusing without requiring deployment of a probe source. Instead, a radio-telemetered vertical receive array (VRA) effectively provided the equivalent waveguide impulse response required for time reversal. The procedure is illustrated in Fig. 1. By reciprocity, the impulse response from a probe source to the source-receive array (SRA) can be obtained by a single element of the VRA at the probe source

location receiving pings from each element of the SRA transmitted sequentially. The multiplexed reception at the VRA element is made available via radio telemetry. After demultiplexing, the multiple impulse responses (one for each SRA element) are time reversed and retransmitted by the SRA yielding a focus at the equivalent probe source location. This procedure then can be generalized to focus SRA transmissions either sequentially or simultaneously at any of the depths of the VRA elements.

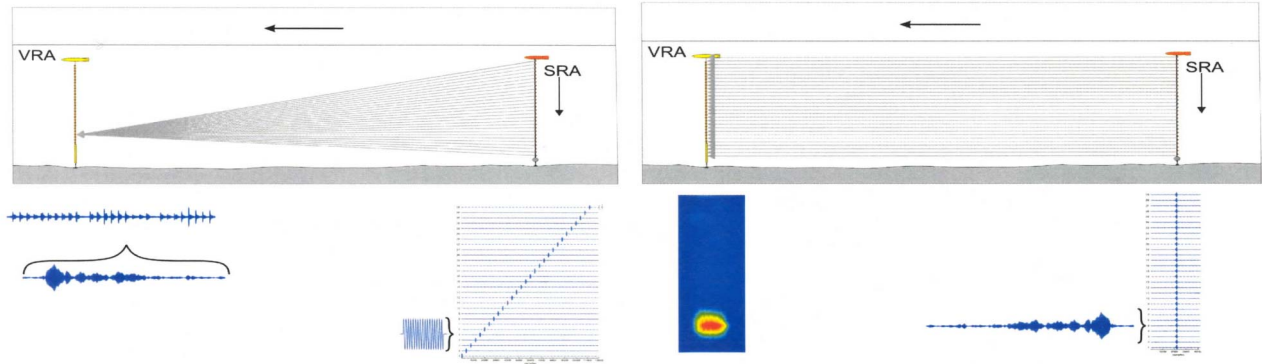


Figure 1. Illustration of the reciprocity-based focusing procedure. (a) Transmit pings sequentially from each element of the source-receive array (SRA). Receive these transmissions at a single element of the vertical receive array (VRA). Make available the multiplexed reception at the VRA element via radio telemetry. (b) After demultiplexing, time reverse and retransmit simultaneously from the SRA the multiple waveguide impulse responses (one for each SRA element). The retransmission focuses at the VRA element from which the impulse responses were extracted.

Focusing at multiple depths was demonstrated during FAF-03 at both 850 Hz and 3.5 kHz in 105 m deep water with a 9 km separation between the SRA and VRA. Fig. 2 shows examples of 3.5 kHz focusing both sequentially at all 32 depths of the VRA elements and simultaneously at 6 depths across the water column.

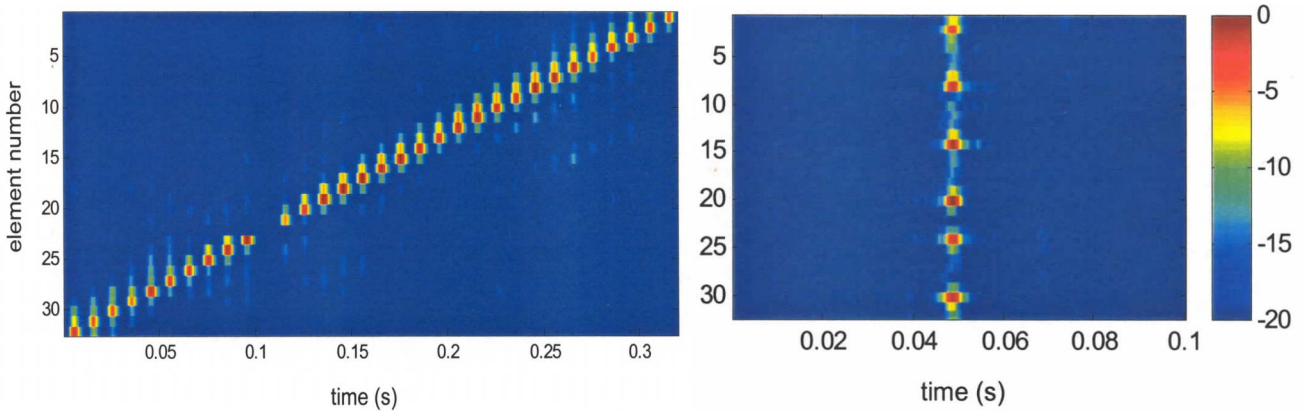


Figure 2. Focusing at 3.5 kHz and multiple depths during FAF-03 using the reciprocity-based focusing procedure. The SRA and VRA were separated by 9 km in 105 m deep water. The panels show the reception from all 32 elements of the VRA. (a) Sequential focusing at all 32 elements. (b) Simultaneous focusing at 6 depths across the water column.

IMPACT / APPLICATIONS

Although this work is at the early concept demonstration stage, there are four natural transition paths for phase conjugation system concepts: (1) ONR (e.g. the Littoral ASW Multistatics Project (LAMP), (2) SPAWAR (e.g. the Low Frequency Active (LFA) and Advanced Deployable System (ADS) programs), (3) NAVSEA (e.g. PMS-411 and the SQS53C program), and (4) NAVAIR (e.g. PMA-299 and the Airborne Low Frequency Sonar (ALFS) program).

RELATED PROJECTS

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PUBLICATIONS

- [1] W.A. Kuperman, W.S. Hodgkiss, H.C. Song, T. Akal, C. Ferla, D.R. Jackson, "Phase Conjugation in the ocean: Experimental demonstration of an acoustic time reversal mirror," J. Acoust. Soc. Am. 103(1): 25-40 (1998). [published, refereed]
- [2] H.C. Song, W.A. Kuperman, and W.S. Hodgkiss, "A time reversal mirror with variable range focusing," J. Acoust. Soc. Am. 103(6): 3234-3240 (1998). [published, refereed]
- [3] W.S. Hodgkiss, H.C. Song, W.A. Kuperman, T. Akal, C. Ferla, and D.R. Jackson, "A long range and variable focus phase conjugation experiment in shallow water," J. Acoust. Soc. Am. 105(3): 1597-1604 (1999). [published, refereed]
- [4] H.C. Song, W.A. Kuperman, W.S. Hodgkiss, T. Akal, and C. Ferla, "Iterative time reversal in the ocean," J. Acoust. Soc. Am. 105(6): 3176-3184 (1999). [published, refereed]
- [5] J.S. Kim, H.C. Song, and W.A. Kuperman, "Adaptive time-reversal mirror," J. Acoust. Soc. Am. 109(5): 1817-1825 (2001). [published, refereed]
- [6] S. Kim, G. Edelmann, W.S. Hodgkiss, W.A. Kuperman, H.C. Song, and T. Akal, "Spatial resolution of time reversal arrays in shallow water," J. Acoust. Soc. Am. 110(2): 820-829 (2001). [published, refereed]
- [7] W.S. Hodgkiss, J.D. Skinner, G.E. Edmonds, R.A. Harriss, and D.E. Ensberg, "A high frequency phase conjugation array," Proc. OCEANS 2001: 1581-1585 (2001). [published]
- [8] J.S. Kim, W.S. Hodgkiss, W.A. Kuperman, and H.C. Song, "Null-broadening in a waveguide," J. Acoust. Soc. Am. 112(1): 189-197 (2002). [published, refereed]
- [9] G.F. Edelmann, T. Akal, W.S. Hodgkiss, S. Kim, W.A. Kuperman, and H.C. Song, "An initial demonstration of underwater acoustic communication using time reversal," IEEE J. Oceanic Engr. 27(3): 602-609 (2002). [published, refereed]

- [10] W.A. Kuperman, S. Kim, G.F. Edelmann, W.S. Hodgkiss, H.C. Song, and T.Akal, "Group and phase speed analysis for predicting and mitigating the effects of fluctuations," pp. 279-286, appears in: N.G. Pace and F.B Jensen (eds.). *Impact of Littoral Environmental Variability on Acoustic Predictions and Sonar Performance*. The Netherlands: Kluwer Academic Publishers (2003). [published]
- [11] S. Kim, W.A. Kuperman, W.S. Hodgkiss, H.C. Song, G.F. Edelmann, and T. Akal, "Robust time reversal focusing in the ocean," *J. Acoust. Soc. Am.* 114(1): 145-157 (2003). [published, refereed]
- [12] H.C. Song, W.A. Kuperman, W.S. Hodgkiss, T. Akal, and P. Guerrini, "Demonstration of a high frequency barrier with a time reversal mirror," *IEEE J. Oceanic Engr.* 28(2): 246-249 (2003). [published, refereed]
- [13] S. Kim, W.A. Kuperman, W.S. Hodgkiss, H.C. Song, G. Edelmann, and T. Akal, "Echo-to-reverberation enhancement using a time reversal mirror," *J. Acoust. Soc. Am.* (2003). [submitted]
- [14] G.F. Edelmann, "Underwater acoustic communications using time reversal," Scripps Institution of Oceanography, University of California, San Diego (July 2003). [Ph.D. thesis]